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Respiratory effects of chlorine gas

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Beach, F. X. M., Sherwood Jones, E., and Scarrow, G. D. (1969). *Brit. J. industr. Med.*, **26**, 231-236. **Respiratory effects of chlorine gas.** Seven chemical workers who were accidentally exposed to chlorine gas in separate accidents were investigated. The usual symptoms were cough, dyspnoea, and chest pains, the symptoms starting within 10 minutes of exposure and lasting two to eight days. Chest radiographs showed congestion, consolidation, and nodules; lung oedema was also present in a severe case. These changes usually cleared within one week but in the severe case persisted for 10 weeks. Three patients had respiratory failure. Hypoxaemia was found in four patients and was quickly corrected by oxygen therapy in three of them, but in the severe case hypoxaemia persisted for four days despite continuous oxygen therapy. All the patients recovered completely.

Half a million tons of chlorine are produced in this country every year; the bulk of this is manufactured locally. Despite this, serious accidents during manufacture or transportation are rare. Jones (1952) reported 820 cases of chlorine gassing from the local factories, but only seven cases were clinically severe and none of his patients died. In 1967 a man aged 49 died from lung oedema three hours after gassing, and this, as far as we know, is the only fatality in this region (Whitehead, personal communication). During the past year we have studied the natural history, chest radiograph, and arterial blood of process workers exposed to chlorine in our local factories.

Clinical findings

Table 1 shows the clinical findings on our seven patients, one of whom had chronic bronchitis (M.R.C. definition, 1965). Six men had mild or moderate illnesses which lasted two to eight days. The usual symptoms were conjunctivitis, cough, breathlessness, and chest pains. With one exception (patient no. 6) the onset of the symptoms followed within 10 minutes of exposure. The illness threatened the life of our first patient, and the natural history can best be described by referring to this case.

Case history

A 44-year-old process worker was exposed to a high concentration of gas when closing a valve which was allowing liquid chlorine to leak on to the floor. He quickly began to choke and developed severe dyspnoea, a persistent cough, and chest pain. His eyes were smarting. The patient was given oxygen and was transferred to the Intensive Care Unit 10 hours later. He was cyanosed, his breathing was rapid and shallow, and he was coughing up pink, frothy sputum. The conjunctivae were markedly injected and numerous coarse crepitations could be heard. On the second day the patient had a severe headache and pains in the limbs and chest which persisted for two days. He remained critically ill for 48 hours and then gradually improved. The axillary temperature was 100°F. (37·8°C.) on days 6 and 7, presumably due to respiratory infection; the patient was given tetracycline, 250 mg. 6-hourly for five days. The sputum was purulent on day 3 but contained no pathogens.

For nine days the patient was given continuous oxygen. On days 4 and 5 he was cyanosed when allowed to breathe air. The dyspnoea gradually decreased and by the tenth day there was none at rest. He was discharged from hospital after 13 days. Exercise dyspnoea persisted for five weeks. Chest radiographs taken during the illness and on recovery are shown in the Figure. The blood gas findings are given in Table 3. During the illness the blood pressure and electrocardiogram remained normal. No abnormal

TABLE 1

CLINICAL FINDINGS

Patient	Age (yrs)	Chronic bronchitis	Site and duration of gassing (min.)	Severity of symptoms	Cough	Sputum	Choking sensation	Dyspnoea	Conjunctivitis	Crepitations	Chest pains	Cyanosis	Headache	Muscle pains	Duration of illness (days)
1	44	No	I 5	Severe	Yes	Pink, frothy for 3 days, mucoid 4 days	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	9
2	34	No	I 3	Moderate	No	Muco-purulent day 2	No	Yes	Yes	Yes	Yes	Yes	Yes	No	3
3	37	No	I 6	Moderate	Yes	None	No	Yes	No	Yes	Yes	Yes	Yes	No	3
4	50	Yes	I 10	Moderate	Yes	Frothy day 1 then muco-purulent for 3 days	No	Yes	Yes	Yes	Yes	Yes	No	No	5
5	60	*	O 10	Mild	No	None for 3 days, muco-purulent for 2 days	No	Yes	No	No	Yes	No	No	No	4
6	45	*	I 45	Mild	Yes	None	No	Yes	Yes	Yes	Yes	No	Yes	No	8
7	48	*	O 10	Mild	Yes	Little mucoid day 2	No	No	No	No	No	No	No	No	3

*No data available
I = indoors.
O = outdoors.

haemoglobin pigments were found in the blood and the S.G.O.T. was normal.

In addition to continuous oxygen therapy the patient was treated with prednisolone, initially 40 mg. daily for three days, then 30 mg. a day for a further three days. The dose was gradually reduced and stopped after a total of 12 days.

The follow-up was concluded after two months. There were no residual symptoms or signs and the chest radiograph and lung function tests were normal.

Radiographic findings

Anteroposterior radiographs of the chest were taken on admission and were usually repeated daily. The changes in the radiograph were as follows: congestion, oedema, consolidation, and nodules. Oedema was seen in the severe case only (Figure). Congestion, consolidation or basal nodules were seen in the remaining patients who had mild or moderate illnesses. The radiographic findings are summarized in Table 2. All these acute changes cleared within a week, except in patient no. 1, whose chest film returned to normal after 10 weeks (Figure). Similar radiographic findings have been described previously (Schatzki, 1962).

Laboratory methods

*p*H was determined electrometrically using a capillary electrode (Siggaard Andersen, Engel, Jørgensen, and Astrup, 1960). The electrode was calibrated with two phosphate buffers of *p*H 7·416 and 6·839 at 38°C. (Semple, Mattock, and Uncles, 1962). The normal range was taken as 7·35-7·45.

$PaCO_2$ was measured directly with an electrode (Severinghaus and Bradley, 1958), calibrated with two gas mixtures, the CO_2 contents of which were determined on the Haldane apparatus (Douglas and Priestley, 1948). Normal values were taken as 33-44 mm. Hg. The *p*H and $PaCO_2$ results were used to obtain the base excess or deficit from a nomogram (Siggaard Andersen, 1963).

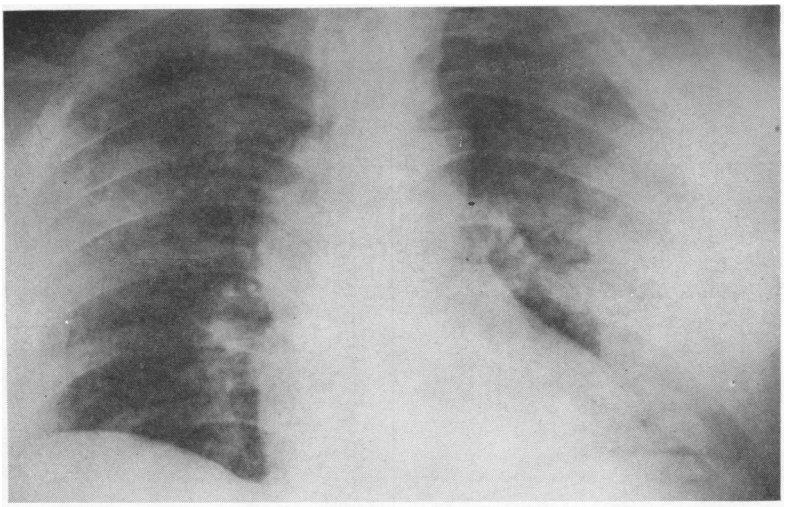
The PaO_2 and PiO_2 were estimated by a Clark-type electrode (Radiometer Ltd., type E5046) calibrated with nitrogen, air, and 100% O_2. When gas rather than blood is used to calibrate the oxygen electrode errors increase, the standard deviation increasing from 5-7 mm. Hg (Flenley, Millar, and Rees, 1967). The alveolar oxygen tension (PAO_2) and alveolar-arterial gradient ($A\text{-}aDO_2$) were calculated from the alveolar gas equations and the equation of Raine and Bishop (1963).

Transfer factor was measured with carbon monoxide

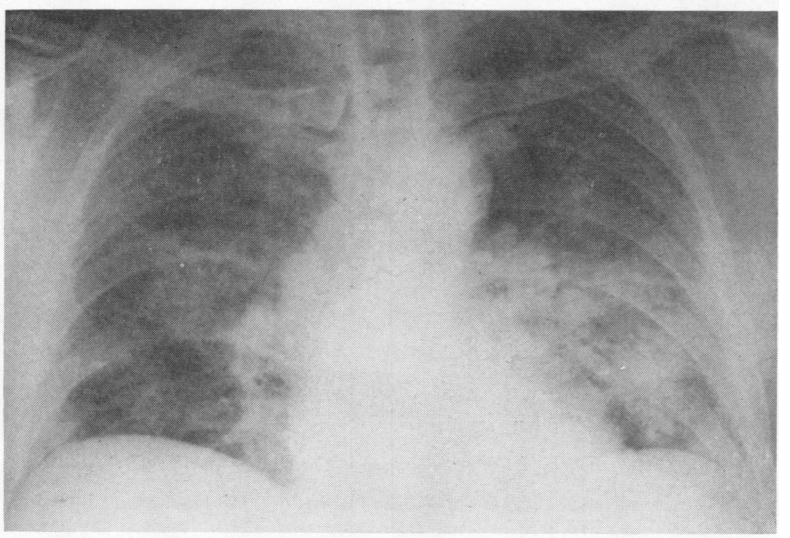
TABLE 2

CHEST RADIOGRAPHS

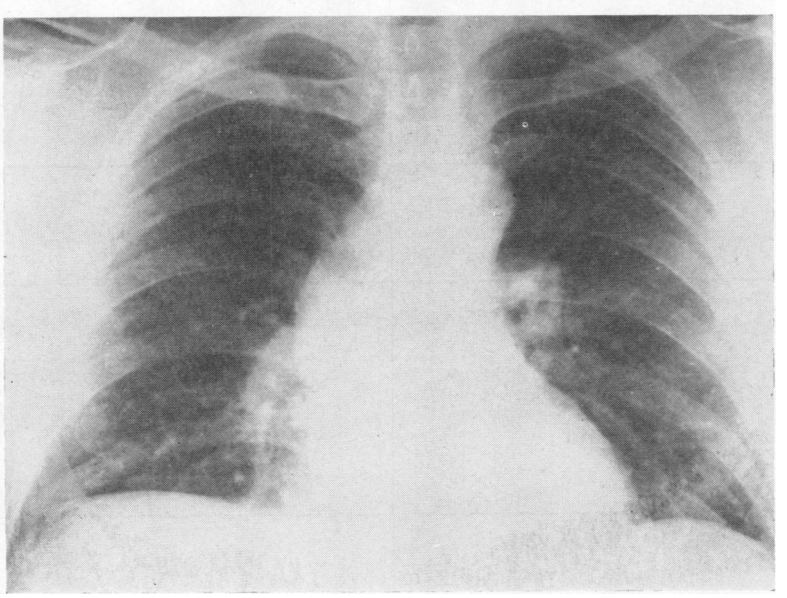
Patient	Findings
1	Extensive bilateral pulmonary oedema on admission, clearing after a few days. Consolidation in mid-zones on day 3, slowly resolving. Lung fields clear after 10 weeks
2	Congestion, clearing in 3 days. Basal nodules and patchy consolidation
3	Congestion only, clearing in 4 days
4	Congestion only, clearing in 6 days
5	Congestion on admission, clearing after a few days. Basal nodules and pleural thickening
6	Congestion on admission, clearing in 5 days
7	A little congestion, clearing in 3 days



(*a*)



(*b*)



(*c*)

FIGURE Chest radiographs on first patient: (*a*) pulmonary oedema on day 1; (*b*) consolidation on day 7; and (*c*) normal radiograph two months later.

TABLE 3

BLOOD GAS RESULTS

Case and day of study	*Hours*	*Inspired oxygen (l./min.)*	*Arterial blood*				*PiO_2 (mm. Hg)*	*PaO_2 (mm. Hg)*	*Observed A-aDO_2 (mm. Hg)*	*Predicted A-aDO_2 (mm. Hg)*
			PaO_2 (mm. Hg)	*$PaCO_2$ (mm. Hg)*	*pH*	*Base (mEq/l.)*				
1										
Day 1	0	Air	45	24	7·38	−10				
	3	7	70	27	7·38	− 8				
2	0	7	65	21	7·39	−11				
	6	7	70	34	7·37	− 4				
5		7	154	30	7·46	− 2				
6		7	77	26	7·48	− 4				
7		7	145		7·45					
2										
Day 1	0	Air	54	22	7·39	−11				
	3	7	110	29	7·39	− 6				
3										
Day 1		Air	65	17	7·49	−11	152	132	67	9
2	0	10	97	36	7·42	0	375	330	233	71
	3½	10	193	39	7·38	− 1				
3		10	210	33	7·42	− 2				
4										
Day 1		10		48	7·37	4				
5										
Day 1		Air	55	36	7·29	− 8	150	105	50	17
2		6	160	33	7·39	− 4				
3		4	190	25	7·41	− 8				
4		4	217	33	7·45	0				
5		4	145	36	7·40	− 2	210	167	22	35
6	0	4	145	30	7·41	− 5	240	203	58	45
	3	Air	111	27	7·42	− 6	148	116	5	11
6										
Day 1	0	Air	84	17	7·37	−15	152	141	57	11
	5	6	60	15	7·37	−18				
2		6	145	32	7·41	− 3				
3		6	130	28	7·40	− 6	218	183	53	14
5		6	171	29	7·43	− 4				
7		4	150	26	7·40	− 7	254	222	72	35
7										
Day 1		6	143	35	7·44	1	270	227	34	16
2		6	54	32	7·43	− 2	163	126	72	20
3		8	140	28	7·47	− 3	217	182	42	39

TABLE 4

PULMONARY FUNCTION RESULTS AFTER 8 WEEKS' CONVALESCENCE

Patient	*F.V.C. (l.)*	*$F.E.V._1$ (l.)*	*Residual volume (l.)*	*$F.E.V._1$ as % F.V.C.*	*Transfer factor (DLco)*
1	2·1 (50)	1·86 (60)	1·75 (97)	71 (95)	23·1 (81)
2	4·8 (100)	3·6 (95)	1·95 (108)	71 (90)	35·4 (111)
3	4·5 (96)	3·7 (100)	2·0 (105)	79 (101)	31·8 (101)
4	2·75 (70)	1·45 (48)	3·55 (176)	55 (75)	30·7 (104)
6	2·95 (61)	2·0 (57)	1·9 (95)	68 (91)	27·6 (92)
7	4·65 (91)	3·2 (94)	2·1 (95)	67 (90)	30·0 (98)

Figures in parentheses are percent of predicted normal (Cotes, 1965).

(Ogilvie, Forster, Blakemore, and Morton, 1957), normal range 18-33 ml./mm. Hg/min.

Blood gases The blood gas results are shown in Table 3. The arterial *p*H was normal in three men, high in three, and low in one. Six patients had a low $PaCO_2$ and one had hypercapnia. This patient (no. 4) had chronic obstructive airways disease, and the sample was taken when he was breathing oxygen at 10 l./min. The plasma base was normal in two men and low in five; four had a base deficit greater than 10 mEq/l. There was significant hypoxaemia (PaO_2 of 88 mm. Hg or less) in four out of five patients breathing room air. Three of these four patients had a $PaO_2$of less than 60 mm. Hg and therefore by definition these had respiratory failure (Campbell, 1965). In patients 1 and 7 the PaO_2 values were low on days 6 and 2 respectively, when compared with the values on the preceding and following days. No reason was found to account for this change. The hypoxaemia was corrected by giving oxygen, except in the first patient, whose PaO_2 remained below 70 mm. Hg for two days. In five patients the A-aDO_2 was two to five times greater than the normal value on eight determinations, and normal in four. This means that the ventilation-perfusion ratio was usually abnormal.

Treatment

The patients were given oxygen on arrival at the medical centre of the factory and this was continued during their transfer to our unit. We gave oxygen by means of an M-C mask (Catterall, 1960) at flow rates of 4-10 l./min. Because the patients were dyspnoeic and unable to eat a normal diet they were given a liquid diet of milk powder and sugar (Jones and Peaston, 1966). Antibiotics were given to two patients.

Lung function on recovery

Spirometry, lung volumes, and transfer factor were measured on six patients eight weeks after discharge from hospital (Table 4). The results on five men were normal. Patient no. 4 showed an obstructive pattern with increased residual volume but a normal transfer factor.

Discussion

The respiratory effects of chlorine have been recognized since it was used as a poison gas in the First World War. Gassing has since occurred at the place of manufacture (Jones, 1952) or during transport (Chasis, Zapp, Bannon, Whittenberger, Helm, Doheny, and MacLeod, 1947; Joyner and Durel, 1962).

The respiratory effects were well described by Drinker (1945): 'The gas affects the mucosa from the top of the respiratory tract to the alveoli. This means increased formation of mucus, turgescence of the mucosa, perhaps direct stimulation of the smooth muscle of the bronchioles with resulting contraction. All this results in blockage of air passages and anoxia of alveolar capillaries; but here again the one most prominent effect is increased delivery of proteinized fluid, which adds to the exclusion of air and the cycle of disaster.'

The chief physiological disturbance is hypoxaemia, which was recognized by Haldane and Priestley (1935) and confirmed by Chasis and his colleagues (1947). Our own results show that in severe poisoning hypoxaemia may not be corrected by giving oxygen at atmospheric pressure. The measurements of the alveolar-arterial oxygen gradient suggest that this investigation is a valuable guide to the severity of the poisoning. In most of our patients the $PaCO_2$ was low, and hence alveolar ventilation was increased.

Oxygen therapy is the most important treatment. This may be given either from a face mask which delivers about 60% oxygen, or by breathing oxygen under a small positive pressure (Barach, 1944), or by means of intermittent positive pressure breathing from a powered respirator (Flake, 1964). If a patient has chronic obstructive airways disease then the oxygen therapy should be controlled by measurements of $PaCO_2$.

Antibiotics should be given if the sputum is purulent. We gave our first patient prednisolone, anticipating that it would suppress the inflammatory lung reaction, but we have no proof that this happened. Since chlorine gassing may cause bronchospasm with wheeze and reversible airways obstruction, bronchodilator drugs were used by Barach (1944) and Flake (1964) but were not given to our patients.

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